Access Spacing and Accidents

A Conceptual Analysis

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ABSTRACT

This paper develops a method for predicting the safety of arterial roads based on arterial traffic volumes, access road (i.e., driveways and intersecting streets) volumes, and access density. This procedure applies the long-established relationship between intersection accidents and the product of conflicting traffic volumes. The simplifying assumption that access roads have roughly equivalent volumes makes it possible to provide safety indices that relate only to the change in access density; these indices are generally consistent with those reported in *NCHRP Report 420, Impacts of Access Management Techniques.* They show that the increase in accidents is equal to the square root of the increase in access density.

INTRODUCTION

More than 40 years of accident analyses have found that the accident rates—expressed as accidents per million vehicle miles of travel—increase as the number of access points per mile increases. The specific effects of access density, however, vary among individual studies. Differences reflect many factors, especially the intersecting volumes on crossroads and driveways.

Along most urban and suburban highways, intersection-related accidents now constitute the majority of all accidents (*1*). Box, in a study of accidents in Skokie, Illinois, found that 40% of all road accidents in the city occurred at 30 locations (*2*). The percentages are probably even higher along suburban roads lined with strip commercial developments and frequent driveways. Thus, it is reasonable to assume that intersection accident frequencies and rates provide a reasonable basis for estimating arterial road safety.

This paper reviews existing intersection safety analysis methods and shows how they can be extended to a series of access points along a section of highway. It assesses the safety effects of increasing or reducing driveway spacings and compares findings with previous research studies. Finally, it sets forth guidelines for application.

PREDICTING INTERSECTION ACCIDENTS

The safety of intersection accidents can be assessed in terms of either the sum or product of vehicles entering an intersection. The sum has been widely used, although research efforts in the United States and the United Kingdom have found the product to be a good predictor of accidents.

Sum

The traditional method of assessing safety relates annual accidents to the sum of the vehicles entering an intersection, expressed in millions. Box, for example, reported 3-year accident rates ranging up to 3.0 accidents per million entering vehicles at high accident intersections (*2*).

Federal Highway Administration studies found rates at urban stop-sign controlled intersections that ranged from 1.3 for less than 5,000 ADT to 8.0 for more than 20,000 ADT (*1*).

Product

Several studies have found that intersection accidents relate to the product of intersecting traffic flows:

California

A 1953 study by McDonald (*3*) analyzed accident experience over periods of 6 months to 5 years at the 60 at-grade intersections along 180 miles of rural, divided expressways in California. Most intersections had stop control on the minor road, although a few signalized intersections were included. Divided highway volumes ranged from 7,000 to 29,000 vehicles per day and crossroad volumes ranged up to 2,400 vehicles per day. The study found that an exposure index based on the product of intersecting volumes was appropriate to use. The following relationship was developed:

$$N = 0.000713\, V_d^{0.455}\ V_c^{0.633} \tag{1}$$

where:

N = expected accidents per year
V_d = volume on divided highway, veh. per day
V_c = access volume, veh. per day

Both exponents were under 1.00. The exponent for the crossroad volume was larger than the exponent for the divided highway volume, indicating a greater sensitivity to crossroad volumes.

Ohio

A 1964 study by Priest (*4*) analyzed 3 years of accident data for 316 at-grade intersections on divided highways with partial or no control of access. This study found that the accident frequency increases with the product of intersecting volumes. Table 1 shows that the estimated number of accidents per intersection based on the California and Ohio models is generally similar.

United Kingdom

A 1967 study by Colgate and Tanner analyzed the frequency of “junction” type accidents resulting in personal injury at 139 rural 3-way junctions (*5*). “Junction” type accidents

TABLE 1 Expected Number of Accidents per Intersection—California and Ohio Models

Minor Road ADT	Divided Highway ADT 7,500		Divided Highway ADT 10,000	
	California	(Ohio)	California	(Ohio)
100	0.8	(0.3)	1.0	(0.4)
500	2.3	(2.2)	2.6	(2.8)
1,000	3.6	(3.8)	4.1	(4.2)
2,000	5.6	(5.2)	6.4	(7.4)
3,000		(8.2)		

Source: Harwood, D., Pietrucha, MT, Wooldridge, M.D., Brynia R.E. and Fitzpatrick, *NCHRP Report 375*, *Median Intersection Design*, Transportation Research Board, National Research Council, Washington, DC, 1995.

involved a collision between a vehicle traveling straight through the junction and a vehicle turning into and out of the minor road. These accidents represented about two-thirds of the accidents that were reported. The frequency of accidents varied approximately with the square root of the product of the two flows involved.

The accident rates (R_L and R_R) were computed separately for the conflicting movements involved on the left and right corners of the intersection separately.

$$R_L = A_L / Q^a q_L^b \qquad R_R = A_R / Q^c q_R^d \tag{2}$$

where:

A_L, A_R = observed accident frequencies
Q = through volumes involved
q_L *and* q_R = the turning volumes involved

The values of a, b, c, and d respectively were 0.47, 0.66, 0.82, and 0.27. Since none of them differed significantly from 0.5, this value was used. Corresponding coefficients in an earlier study were 0.88, 0.36, 0.62, and 0.56 respectively.

Hauer

A 1988 study by Hauer, Ng, and Lovell (*6*) also found that the product of intersecting volumes was better related to intersection accidents than to the sum of entering vehicles at signalized intersections. In the model $N = K\, V_1^a\, V_2^b$, the exponents a and b varied for individual conflicts, with median values of about 0.50 for each.

Summary Comparison

The comparative accident exposure indices for various artery and cross road volumes based upon the *sum* and *product* of intersecting volumes are given in Table 2. The

TABLE 2 Comparative Accident Exposure Indices

Major Volume	Minor Volume	Arithmetic Mean	Geometric Mean
1	1	1.0	1.0
2	1	1.5	1.4
3	1	2.0	1.7
4	1	2.5	2.0
5	1	3.0	2.2
10	1	5.0	3.2
50	1	25.5	7.1
100	1	50.5	10.0
1000	1	500.5	31.6

Source: Computed

volumes are given in relative terms, and the exposure indices are based upon the arithmetic and geometric means respectively.

There is little difference in the exposure indices when the volumes on the artery are approximately equal. However, when the artery volumes are more than 4 times the volumes on the intersecting street, the exposure index becomes overwhelmingly dominated by the artery volume when the arithmetic mean is utilized.

Thus, using the sum of entering volumes in analyzing the accident exposure of a series of driveways along a road would produce misleading results. The volume product, based upon the geometric mean, appears to be a more realistic measure. This will become more apparent from the discussion that follows.

ACCIDENT POTENTIALS ALONG AN ARTERIAL

The cumulative safety effects of a series of access points along an arterial road can be estimated by applying either of the two intersection analysis models—sum or product. The following discussion shows how accident "exposure indices" can be derived from each.

Potential Related to the Sum of Entering Vehicles

The number of accidents per year at any intersection is commonly expressed as a function of the number of entering vehicles. The basic equation is as follows:

$$N = K_j (V_1 + V_2) \qquad (3)$$

where

N = Expected accidents per year
V_1 = Artery volume, veh/day
V_2 = Crossroad volume, veh/day
K_j = Normalizing calibration constant to account for number of days per year, volumes expressed in millions of vehicles, and likely accident expectancy.

If there are n intersections (or access points) along a section of road and the artery volumes remain constant, the expected intersection (driveway) accidents along a stretch of road would logically represent the sum of each individual intersection's accident experience:

$$N(\text{Over } n \text{ locations}) = K_1 \left[(V_1 + V_{2-1}) + (V_1 + V_{2-2}) + \ldots + (V_1 + V_{2-n})\right] \quad (4)$$

$$= K_1 \left[n\, V_1 + \sum_{1}^{n} V_2\right] \quad (5)$$

where

V_1 = artery volume
V_{2-1} etc. = crossroad volumes
K_1 = calibration constant to convert exposure to annual accidents
N = expected accidents per year.

Thus, for an arterial roadway carrying 25,000 vehicles per day, one crossroad carrying 10,000 vehicles per day, and nine intersecting driveway volumes totaling 3,000 vehicles per day, the relative accident exposure per mile based upon the preceding equations would be as follows:

***Case 1*:**	10 access points/mile			
	(a) Intersecting road	25,000 + 10,000	=	35,000
	(b) Intermediate Access Points	9(25,000) + 3,000	=	228,000
	TOTAL "exposure"			263,000
***Case 2*:**	60 access points/mile			
	(a) Intersection	25,000 + 10,000	=	35,000
	(b) 59 Intermediate Access Points	59(25,000) + 3,000	=	1,478,000
	TOTAL "exposure"			1,513,000

Table 3 summarizes the likely accident exposure for various driveway access volumes per mile, while holding the artery and crossroad volumes constant. In this table, increasing the access density from 10 to 60 per mile results in an approximate 5.5 to 5.8 times increase in exposure. This is because the total volumes involved are dominated by the artery volumes—for an access volume of 100/mile, there would be nearly the same exposure as that for access volumes of 20,000 per mile. This condition is not real. Thus, the model should not be applied in practice.

TABLE 3 Relative Accident Potential Based on Sum of Entering Volumes for 25,000 on Artery, 10,000 on Cross Road Intersection, and Varying Access Volumes

	Relative Accident Exposure Indices		
Total Access Vol/Mile	**9 Access Points (+ 1 Intersection)**	**59 Access Points (+ 1 Intersection)**	**Ratio**
100	260,100	1,510,100	5.81
1,000	261,000[a]	1,511,000[b]	5.79
2,000	262,000	1,512,000	5.78
3,000	263,000	1,513,000	5.75
4,000	264,000	1,514,000	5.73
5,000	265,000	1,515,000	5.72
7,500	267,500	1,517,500	5.67
10,000	270,000	1,520,000	5.63
20,000	280,000	1,530,000	5.46

Source: Computed

Examples

[a] (25,000 + 10,000) + [9 (25,000) + (1,000)]
= 35,000 + [225,000 + 1,000]
= 261,000

[b] (25,000 + 10,000) + 59 (25,000) + 1,000
= 60 (25,000) + 11,000
= 1,500,000 + 11,000 = 1,511,000

Potential Related to the Product of Entering Vehicles

The annual accidents at any intersection can be expressed as a function of the product of the volume of entering vehicles as follows:

$$N = K_2 V_1^a V_2^b \tag{6}$$

where:

N = expected accidents/year
V_1 = artery volume, veh per day
V_2 = crossroad volume, veh per day
a and b = exponents
K_2 = calibration constant to convert exposure to annual accidents

Thus, if there are n access points along a section of roadway and the arterial volumes are constant, the expected intersection/driveway accidents per year can be estimated as follows:

$$N = K_2 \quad \{[V_1^a \ V_{2-1}^b] + [V_1^a \ V_{2-2}^b] + \ldots + [V_1^a \ V_{2-n}^b]\} \tag{7}$$

$$N = K_2 \ \{V_1^a \quad [\sum V_{2i}^b]\} \tag{8}$$

where:

N = expected annual intersection accidents per year between points 1 and n.
K_2 = calibration constant to convert exposure to accidents
V_1 = arterial volume (veh/day)
$V_{2-1}, V_2, \ldots, V_{2-n}$ = crossroad volumes (veh/day)

Note that if $V_{2-1} = V_{2-2} = \ldots V_{2-n}$

$$N = K_2 \ V^a n \ V^b \tag{9}$$

The following analysis example assumes exponents of 0.5 for each road—i.e., the accident exposure is a function of the geometric mean of the product of the traffic volumes entering an intersection. It also uses the California exponents of 0.455 for the arterial road and 0.633 for the crossroads.

Exponents of 0.5 for Both Artery and Crossroads

The relative accident exposure per mile would be computed as follows for an arterial roadway carrying 25,000 vehicles per day, one crossroad carrying 10,000 vehicles per day, and total intersecting driveway volumes of 3,000 vehicles per day. These calculations assume that the driveway volumes would be approximately equally divided among the driveways along the road.

Road
Case 1–10 access points/mile

(a) Intersecting road $(25{,}000)^{0.5} \ (10{,}000)^{0.5}$ = 15,811
(b) 9 intermediate access points $(25{,}000)^{0.5} \ (9) \left(\frac{3,000}{9}\right)^{0.5}$ = <u>25,984</u>

TOTAL 41,795

Case 2–60 access points/mile

(a) Intersecting road $(25{,}000)^{0.5} \ (10{,}000)^{0.5}$ = 15,811
(b) 59 intermediate access points $(25{,}000)^{0.5} \ (59) \left(\frac{3,000}{59}\right)^{0.5}$ = <u>66,519</u>

TOTAL 82,330

TABLE 4 Relative Accident Potential Based on Product of Entering Volumes - 1: 25,000 on Artery, 10,000 on Cross Road Intersection, and Varying Access Volumes (Condition 1—Exponents of 0.5 for Each Intersecting Volume)

	Relative Accident Exposure Indices		
Total Access Volume/Mile	9 Access Points +1 Intersection	59 Access Points +1 Intersection	Ratio
100	20,554	27,956	1.21
1,000	30,811	54,244	1.76
2,000	37,024	70,124	1.80
3,000	41,792	82,330	1.97
4,000	45,811	92,621	2.02
5,000	49,352	101,687	2.06
7,000	56,890	120,943	2.13
10,000	63,245	137,258	2.17
20,000	82,893	187,562	2.26

Source: Computed

Table 4 summarizes the likely accident exposure for various driveway access volumes per mile, while holding the cross road volumes constant. Increasing the access density from 10 to 60 points per mile results in an approximate 1.2 to 2.3 time increase in accident exposure: This ratio rises with increasing access volumes; when access volumes per mile are 100 or less, the effects of additional access points on accidents are minimal.

Exponents of 0.455 for Artery and 0.633 for Cross Roads

Table 5 gives the accident exposure indices for the same mix of arterial, cross road and access drive volumes, based upon the California exponents. Increasing the number of access points from 10 to 60 per mile results in a 1.1 to 1.8 increase in the accident exposure index. It should be noted that as the intermediate access volumes approach zero, there is little difference in the accident likelihood as access density increases.

ESTIMATING EFFECTS OF CHANGES IN ACCESS DENSITY

A major goal of access management is to improve safety by controlling and consolidating access. The “product” accident exposure concept can be readily applied to estimate the safety benefits of consolidating or decreasing the number of access points along an arterial road. The computations can be simplified if it is assumed that intermediate access volumes are about the same.

TABLE 5 Relative Accident Potential Based on Product of Entering Volumes - 2: 25,000 on Artery, 10,000 on Cross Road Intersection and Varying Access Volumes (Condition 2—Exponents of 0.455 for Artery and 0.633 for Cross Volumes)

	Relative Accident Exposure Indices		
Total Access Volume/Mile	9 Access Points +1 Intersection	59 Access Points +1 Intersection	Ratio
100	37,130	41,823	1.13
1,000	51,914	69,600	1.34
2,000	61,716	89,140	1.44
3,000	69,785	105,238	1.51
4,000	76,914	119,442	1.55
5,000	82,480	132,386	1.61
7,500	92,825	161,139	1.65
10,000	110,974	186,509	1.68
20,000	152,645	270,440	1.77

Before consolidation, the expected accidents, N_1, would be as follows over a given section of road:

$$N_1 = K\, n_1\, V_1 \left(\frac{V_2}{n_1}\right)^b \tag{10}$$

where

K = Calibration factor
n_1 = Number of driveways before consolidation
V_1 = Artery volume
V_2 = Total access volume on a given section of road
N_1 = Accidents per year before consolidation

Similarly after consolidation, the expected accident N_2, would be as follows:

$$N_2 = K\, n_2\, V_1^a \left(\frac{V_2}{n_2}\right)^b \tag{11}$$

where n_2 = Number of driveways after consolidation.

Taking the ratio of N_2 to N_1 results in the following formula:

$$(N_2/N_1) = \frac{n_2}{n_1}\left(\frac{n_1}{n_2}\right)^b \tag{12}$$

Note that the other factors (V_1, V_2 and K) cancel out.

If the exponent $b = 0.5$, this relationship becomes:

$$N_2/N_1 = \sqrt{\frac{n_2}{n_1}} \tag{13}$$

This formula suggests that the relative change in accidents is approximately equal to the square root of the ratio between changes in access frequency. Thus, a change from 10 to 20 driveways per mile would result in a 41% increase in accidents.

Table 6 gives the relative changes in accident potential (exposure as the number of access points over a given section of road increases). The values assume

TABLE 6 Anticipated Safety Impacts from Changing Driveway Spacing (for a Given Access Volume)

	b = 0.5		b = 0.633	
Driveway Density Ratio After/Before	**Exposure Ratio After/Before**	**% Change**	**b = 0.633**	**% Change**
0.10	0.32	68	0.43	57
0.20	0.45	55	0.55	45
0.30	0.55	45	0.65	35
0.40	0.63	37	0.71	29
0.50	0.71	29	0.78	22
0.60	0.77	23	0.83	17
0.70	0.83	17	0.88	12
0.80	0.89	11	0.92	8
0.90	0.95	5	0.96	4
1.00	1.00	0	1.00	0
1.50	1.22	22	1.16	16
2.00	1.41	41	1.29	29
2.50	1.58	58	1.40	40
3.00	1.73	73	1.50	50
4.00	2.00	100	1.66	66
5.00	2.24	124	1.81	81
6.00	2.45	145	1.93	93
7.00	2.65	165	2.04	104

Source: Computed

that the total access driveway volumes remain constant and that the individual access volumes would be about equal. The table gives estimated changes for *b* coefficients of 0.5 and 0.633.

The values shown in Table 6 can be used to assess the relative changes in safety from adding or consolidating driveways along a section of roadway.

- A reduction from 50 to 40 driveways per mile—a ratio of 0.80 would result in an 8 to 11% reduction in accident potentials. Reducing the number of driveways by 50% (i.e., $n_2/n_1 = 0.5$) would result in a 22 to 29% decline in the accident potential.
- Doubling the access spacing from 10 to 20 driveways per mile would increase accident exposure by 29% to 41%, an increase from 10 to 60 access points per mile would result in a 1.9 to 2.5 times increase.

Table 7 compares the relative increases in accident rates (annual accidents per million VMT) reported in NCHRP 420 (*7*) with those obtained by the volume product equations. The "safety" analysis gives the rate changes based upon cross-classification of more than 37,500 accidents; the "composite" analysis also considers results of a literature synthesis.

The patterns reported in NCHRP 420 are generally similar to those obtained by the preceding analysis. There is an especially close correspondence between the safety analysis results and the indices based on an exponent of 0.5; increasing driveways from 10 to 60 per mile would result in about a 2.5 times increase in accidents in both cases.

TABLE 7 Comparative Safety Impacts Resulting from Increasing Access Density

	Exposure Indices (1) After		NCHRP 420 (2) Indices (Accidents/VMT)	
Access Density Ratio After/Before	b = 0.5	b = 0.633	Safety Analysis	Composite Values Literature Synthesis and Safety Analysis
1.00	1.00	1.00	1.0	1.0
1.50	1.22	1.16	1.2	1.2
2.00	1.41	1.29	1.4	1.4
2.50	1.58	1.40	1.6	1.6
3.00	1.73	1.50	1.8	1.8
4.00	2.00	1.66	2.1	2.1
5.00	2.24	1.81	2.3	2.5
6.00	2.45	1.93	2.5	3.0
7.00	2.65	2.04	2.9	3.5

(1) Assumes constant total access volume equally distributed among driveways.
(2) Gluck, J., Levinson, H.S., Stover, V., *NCHRP Report 420, Impacts of Access Management Techniques*. Prepared for Transportation Research Board, National Research Council, Washington, DC, 1999.

IMPLICATIONS

Several important findings emerge from the preceding analysis:

(1) The sum of traffic entering an intersection, although commonly used, is not practical for application along a series of driveways along a road; this is because it is too heavily weighted by traffic on the arterial.

(2) The product of intersecting volumes, each raised to about the 0.5 power, provides a reasonable basis for assessing intersection safety. When intersecting crossroad and driveway volumes over a section of highway are known, the cumulative impacts can be computed.

(3) When applicable to a fixed crossing volume per given distance (and generally equal access volumes) the relative safety is equivalent to the square root of the ratio of the changes in access frequency. Therefore, consolidating access points into fewer intersections reduces conflict potentials and increases safety.

(4) The computed safety impacts for changes in access density compare closely with those found in other research studies.

These findings suggest that the cumulative analysis of conflicting traffic volumes (based on the products of intersecting volumes) may provide a more realistic approach to safety than the traditional analyses that are based on vehicle miles of travel.

Obviously, many site specific conditions will influence the actual accident experience along any highway. Horizontal and vertical alignments, sight distances, access road designs, and types of intersection controls will influence safety. However, the "exposure indices" provide a benchmark against which such factors can be assessed. Additional research is desirable to further refine the "models" and to calibrate key coefficients and parameters that translate conflict products into accidents.

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